AFRL-RI-RS-TR-2013-165

WIDEBAND COOPERATIVE SPECTRUM SENSING AND SIGNAL DETECTION (BRIEFING SLIDES)

JULY 2013

INTERIM TECHNICAL REPORT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

STINFO COPY

AIR FORCE RESEARCH LABORATORY
INFORMATION DIRECTORATE

■ AIR FORCE MATERIEL COMMAND ■ UNITED STATES AIR FORCE ■ ROME, NY 13441

NOTICE AND SIGNATURE PAGE

AFRL-RI-RS-TR-2013-165 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

FOR THE DIRECTOR:

/ S /

BRENT HOLMES
Chief, Cyber Operations Branch

/ S /

WARREN H. DEBANY, JR.
Technical Advisor, Information
Exploitation & Operations Division
Information Directorate

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE (*DD-MM-YYYY*)	2. REPORT TYPE	3. DATES COVERED (*From - To*)
JULY 2013	INTERIM TECHNICAL REPORT	MAR 2011 – NOV 2011

4. TITLE AND SUBTITLE
Wideband Cooperative Spectrum Sensing & Signal Detection
(BRIEFING SLIDES)

5a. CONTRACT NUMBER IN-HOUSE
5b. GRANT NUMBER N/A
5c. PROGRAM ELEMENT NUMBER 61102F
5d. PROJECT NUMBER WC3S
5e. TASK NUMBER IH
5f. WORK UNIT NUMBER 01

6. AUTHOR(S)
Daniel Zhou

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory/RIGB
525 Brooks Road
Rome NY 13441-4505

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory/RIGB
525 Brooks Road
Rome NY 13441-4505

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/RI

11. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-RI-RS-TR-2013-165

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited. PA# 88ABW-2011-6198
Date Cleared: 30 NOV 2011

13. SUPPLEMENTARY NOTES

14. ABSTRACT
These presentation slides are provided as an interim report of the in-house project titled “Wideband Cooperative Spectrum Sensing”. The objective of this effort is to develop wideband cooperative spectrum sensing and signal detection techniques. Two sensing steps are used to detect and exploit the signals of interest: Coarse sensing to determine the presence or absence of signals within scanned frequency bands; and fine sensing by exploiting the features of signals.

15. SUBJECT TERMS
Cooperative Spectral Sensing, Energy Detection, Frequency Allocation

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					ALFREDO VEGAIRIZARRY
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPONE NUMBER (*Include area code*)
U	U	U	UU	25	**N/A**

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

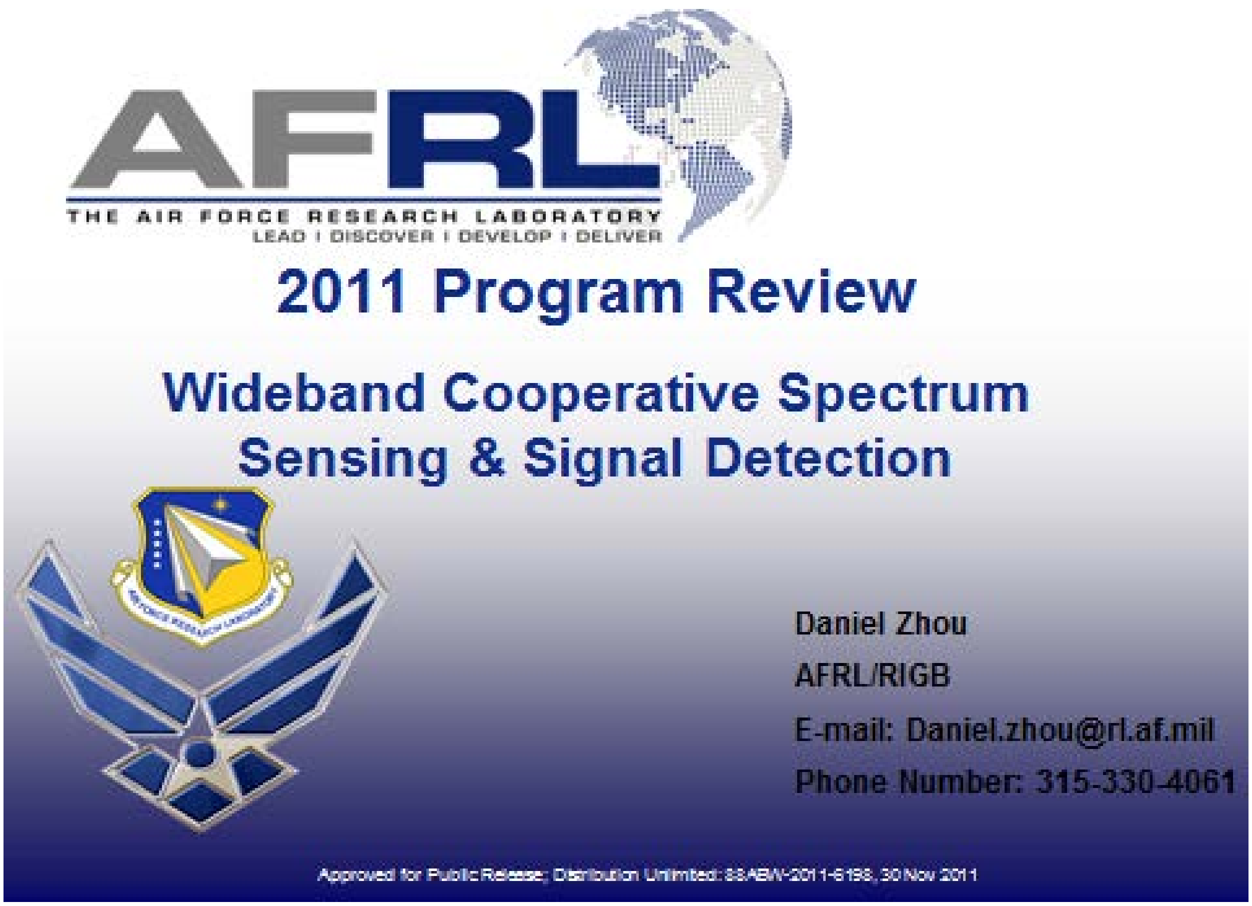
Contents

1 Abstract

This presentation slides are provided as an interim report of the in-house project titled "Wideband Cooperative Spectrum Sensing". The objective of this effort is to develop wideband cooperative spectrum sensing and signal detection techniques. (Slide 3) Two steps sensing are used to detect and exploit the signals of interest: Coarse sensing to determine the presence or absence of signals within scanned frequency bands; and fine sensing by exploiting the features of signals. (Slide 5)

2 Presentation Slides

The presentation slides provided in the next pages summarize the work performed in this in-house project during the FY-12.

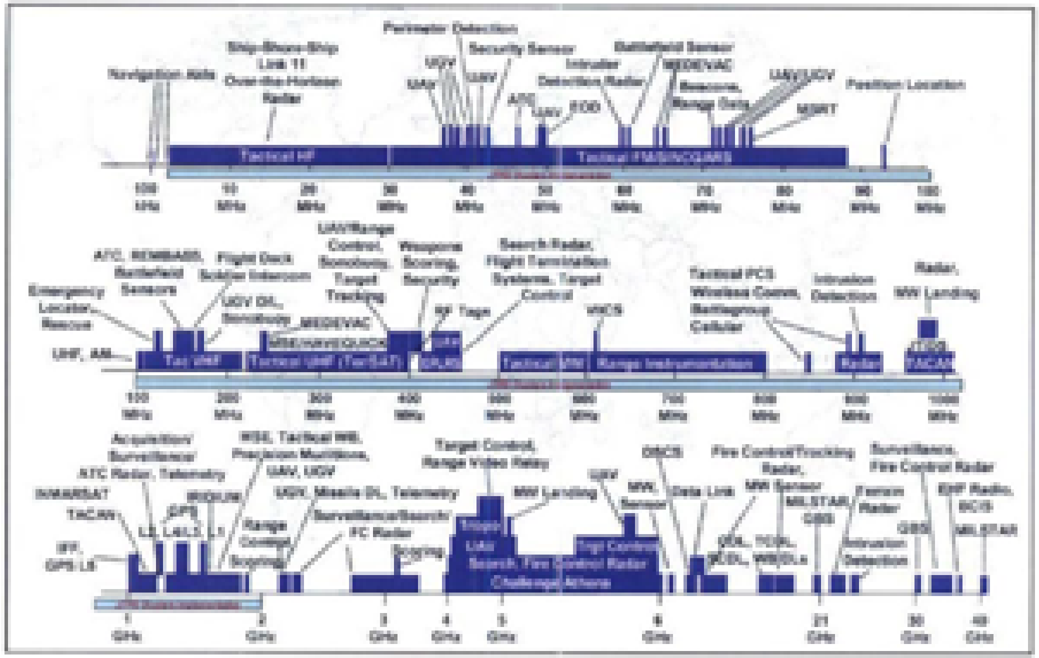


DoD Spectrum Dependence

DoD use spectrum to provide capabilities

- -Communication
- -Telemetry
- -Surveillance
- -Radio location
- -Radio navigation
- -RDT&E

DoD Spectrum Dependence



Source: Ref [1]

2

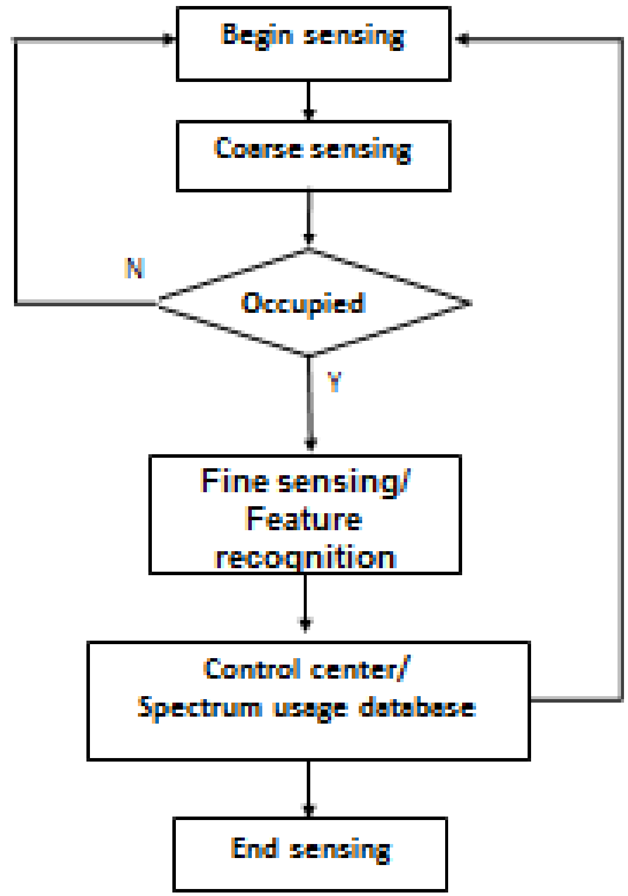
Approved for Public Release; Distribution Unlimited: 88ABW-2011-6198, 30 Nov 2011

Program Objective

- To achieve effective spectral awareness
  - Sensing method capable of making cooperative decisions over multiple frequency bands is essential
  - Many conventional spectrum sensing methods
    - Either single-channel or non-cooperative signal detection
    - Vulnerable to noise uncertainty, fading, and shadowing
- Objective: develop wideband cooperative spectrum sensing and signal detection techniques
  - Spatial diversity: multi-sensors joint decision
  - Spectral diversity: multi-channel detection
  - Effective spectral awareness

Approach

- Cooperative sensing: single sensor to multiple sensors
- Wideband sensing: single-channel to multi-channel
- Two steps sensing to detect and exploit the signals of interest (SOI)
  - Coarse sensing (signal detection): determine the presence or absence of signals within scanned frequency bands
  - Fine sensing (feature recognition): exploiting the features of signals



4

Approved for Public Release; Distribution Unlimited: 88ABW-2011-6198, 30 Nov 2011

Coarse Sensing/Signal Detection

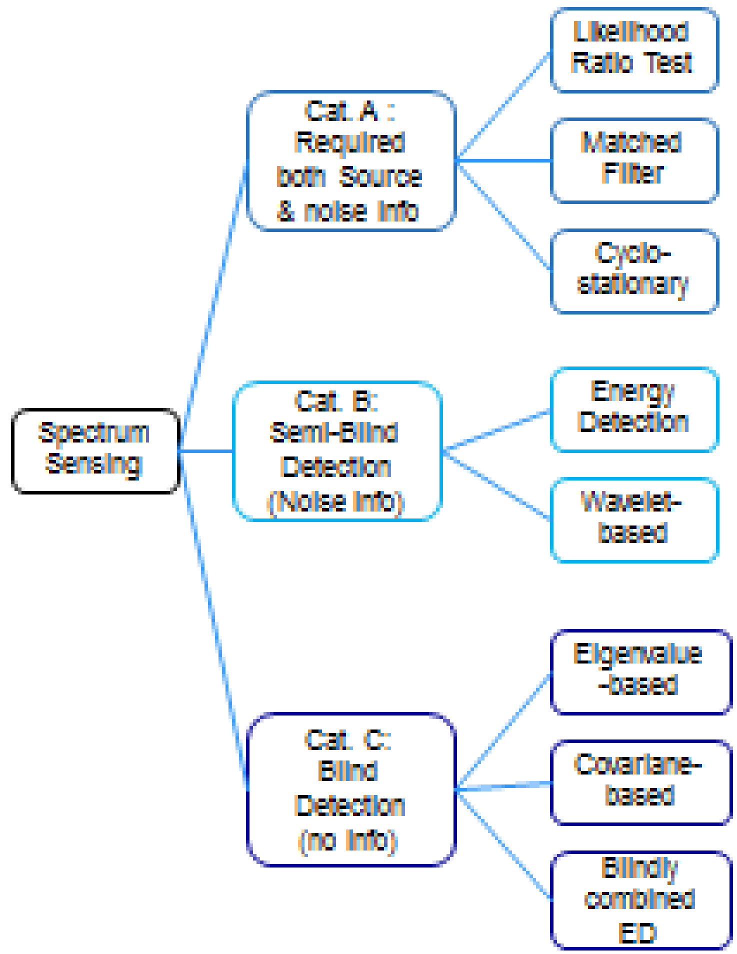
- Objective: quickly & reliably determine the existence of signals in multiple frequency bands by joint detection
- Challenge:
  - No prior information about the signals, blind/semi-blind detection approaches
  - Speed: low computational complexity to achieve quick sensing (low complexity leads to less accurate sensing result)
  - Accuracy: multi-sensors/antennas cooperative sensing to improve the performance
- Two main tasks:
  - Develop a wideband blind/semi-blind sensing method that has the right balance between speed and accuracy
  - Find optimal cooperation strategy to combine sensing results from multiple sensors

Fine Sensing/Feature Recognition

- Objective: exploit & estimate the features (i.e. bandwidth, center frequency, modulation type, etc.) of a signal
  - Fine sensing initiate only when signals been detected in the coarse sensing
  - Some information regarding the noise distribution or signal distribution may already been obtained
  - Known pieces of information can be passed on to fine sensing to assist with features recognition
  - Methods require signal and/or noise information can be used

Sensing Methods

- Spectrum sensing & signal detection is not new
- Cognitive Radio further stimulates its development
- Each method has different requirements for implementation
- Complexity and accuracy of sensing methods is increasing as the information required for detection increasing



7

Approved for Public Release; Distribution Unlimited: 88ABW-2011-6198, 30 Nov 2011

Cooperative Detection

- Constraint of many conventional detection methods
  - Non-cooperative signal detection in single frequency band
  - Sensing reliability degraded due to noise and fading

- Information from multiple sensors can be combined to obtain more accurate decision

Cooperative Sensing		
Distributed	Centralized	
share information among each other but make own decisions	Data feed: each node send raw data, central unit make decision	Decision feed: process data, send only the decision to central unit

Cooperation Strategies

- **Each cooperation strategy has it own decision rule for signal detection**

Strategies	Decision Rule for Detection
Voting	# of votes for detection > # of votes for no detection
OR	Out of N individual decision, any one detected signal
AND	All sensing nodes have to detect signal
Linear combination	Normalized weight assign to local decision according to their SNR, global decision reach by combine weighted local decision

Mathematical Model

- The problem of detection of the signal can be modeled as a binary hypothesis testing problem:

$$\mathcal{H}_0 : \; y_i(n) = w_i(n)$$

$$\mathcal{H}_1 : y_i(n) = s_i(n) + w_i(n)$$

- The performance of the detection algorithm can be summarized with 2 probabilities: probability of detection and probability of false alarm:

$$p_f = \Pr\left(T > \gamma | \mathcal{H}_0\right) \qquad p_d = \Pr\left(T > \gamma | \mathcal{H}_1\right)$$

Small P_f results in higher spectrum efficiency

Large P_d value lead to better chance of detecting signal

Linear Cooperative Sensing

- **Individual sensor**
  - Calculates a summary statistic over an interval of N samples
  - Then statistic is sent to fusion center
- **Fusion center**
  - Assigns a weight to each sensor based on the summary statistic received, then combine them linearly
  - The weight for a particular sensor represents its contribution to the global decision
  - Large weight assigns to those sensors have high-SNR; small weight for sensors with low-SNR

MATLAB Simulation

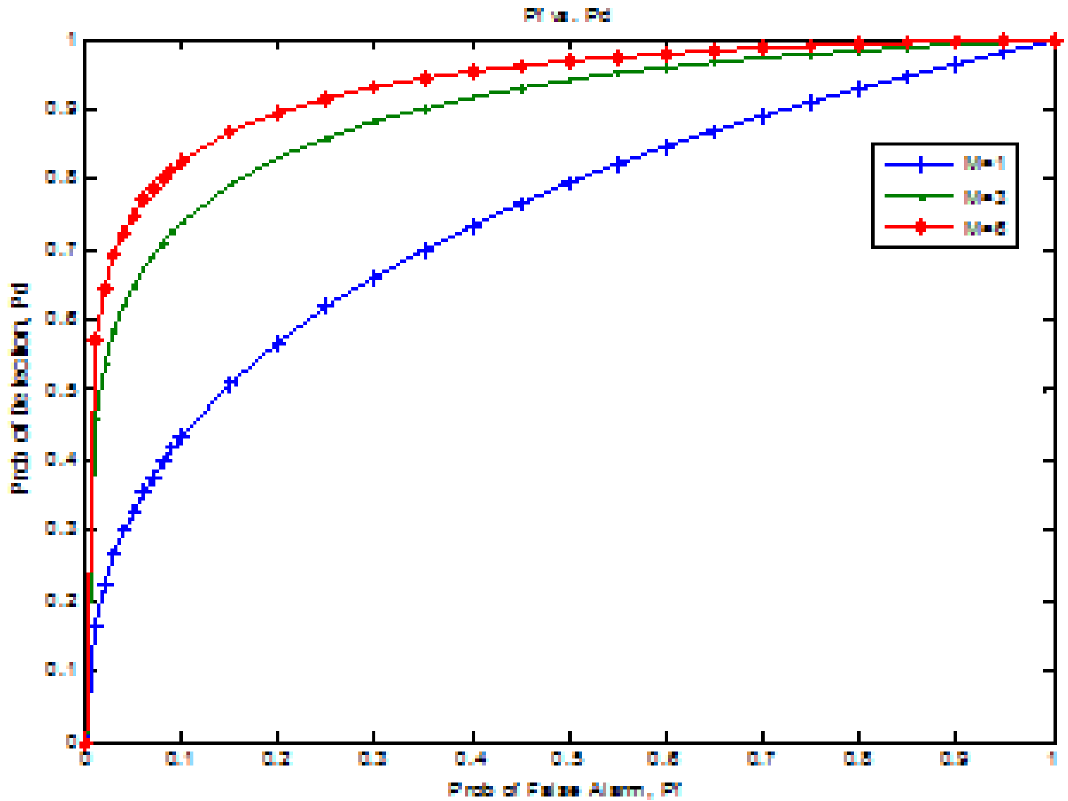
Parameters: Primary user's signal s(k)=1; # of samples: N=20; fixed channel noise variance of 0.5; # of cooperative sensors: M=1, 3, and 6

	M=1	M=3	M=6
SNR (dB)	8.3	{10.4, 9.3, 2.6}	{7.2, 5.1, 10.8, -1.2, 3.6, 9.7}
Sensing noise Variance	1.9	{0.7, 1.0, 0.9}	{09., 1.3, 1.0, 2.0, 1.8, 1.2}

Result of optimal weights and P_d values for a given P_f value

	M=1	M=3	M=6
Weight Vector	1	{0.8348 0.5165 0.1909}	{0.4713; 0.2328 0.6758; 0.0438 0.1285; 0.4986}
Pd (given Pf=0.1)	0.4342	0.7408	0.8265
Pd (given Pf=0.6)	0.8463	0.9599	0.9803

Simulation Plot



Probability of detection vs. Probability of false alarm

13

Wavelet-based Sensing

Goal:

- **Investigate the potential of wavelet transform for wideband cooperative signal detection**

Motivation:

- **Extensive research on wavelet analysis for images and time series**
- **Only limited research has applied wavelet approach to spectral detection**
  - Work by Z. Tian & G.B. Giannakis: Edge detection [2]
  - Work by Y. Hur, & J. Park: Multi Resolution [3]
  - Non-cooperative detection

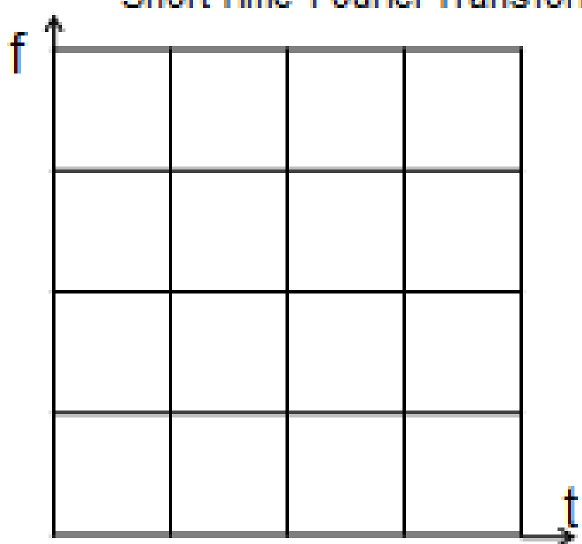
14

Time-Frequency Analysis

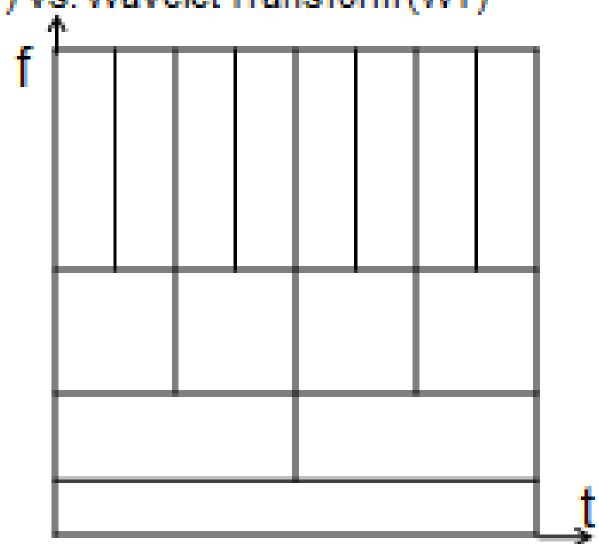
Fourier Transform vs. Wavelet Transform

	Fourier Transform	Wavelet Transform
Processing Signal Type	Stationary	Non-stationary
Provided Information	Frequency	Both time and frequency

Short Time Fourier Transform (STFT) vs. Wavelet Transform (WT)



STFT Resolution



WT Resolution

15

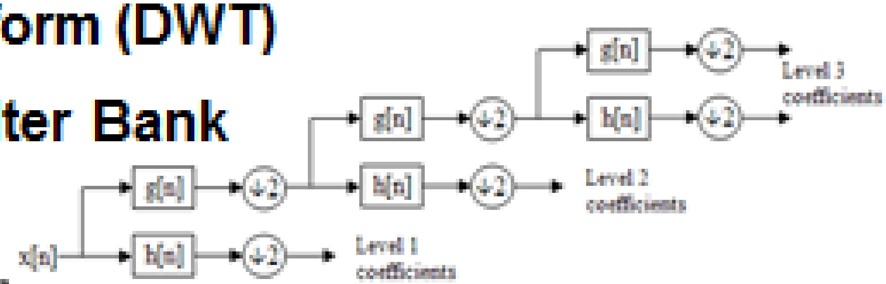
Approved for Public Release; Distribution Unlimited: 88ABW-2011-6198, 30 Nov 2011

Wavelet Transform

- **Continuous Wavelet Transform (CWT)**
  - **The mother wavelet function ψ(*t*)**
  - **The scale factor *a***

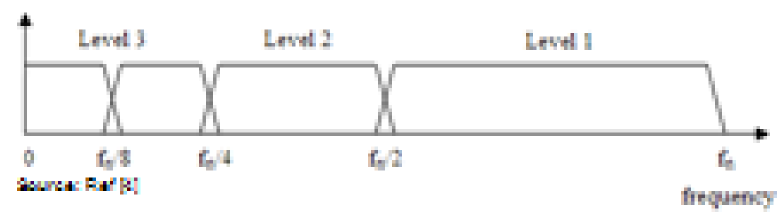
$$X_w(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t)\psi^*\left(\frac{t-b}{a}\right) dt$$

- **Discrete Wavelet Transform (DWT)**
  - **Decomposition by Filter Bank**



A 3 Level Filter Bank

Level	Frequencies	# of Coefficients
3	0 to f_n / 8	n/8
	f_n / 8 to f_n / 4	n/8
2	f_n / 4 to f_n / 2	n/4
1	f_n / 2 to f_n	n/2



DWT Frequency domain representation

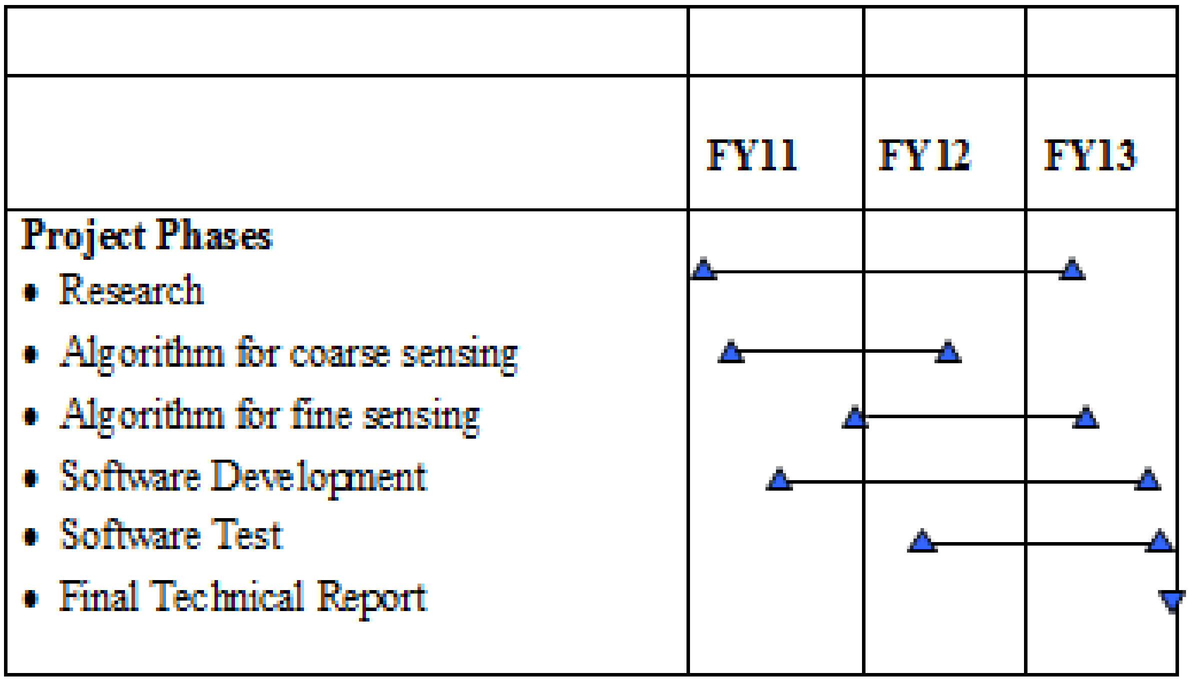
18

Next Step

- **Linear Cooperative Sensing**
  - Extend to wideband detection
- **Wavelet-based Sensing**
  - Continue working on the simulation code to investigate the effectiveness for wideband sensing
  - Feasibility for cooperative sensing
- **Investigating other blind detection methods**
  - Eigenvalue-based
  - Sub-space analysis

17

Program Schedule



3 References

[1] Department of Defense Net-Centric Spectrum Management Strategy, Assistant Secretary of Defense (Networks and Information Integration) Department of Defense Chief Information Officer, 3 August 2006.

[2] Z. Tian and G. B. Giannakis, "A wavelet approach to wideband spectrum sensing for cognitive radios", in Proc. *1st Int. Conf. Cogn.Radio Oriented Wireless Netw. Commun.(CROWNCOM),* Greece, Jun. 8–10, 2006, pp. 1–5.

[3] Y. Hur, J. Park, W. Woo, K. Lim, C.-H. Lee, H. S. Kim, and J. Laskar, "A wideband analog multi-resolution spectrum sensing (MRSS) technique for cognitive radio (CR) systems," in Proc. *IEEE Int. Symp. Circuits Systems (ISCAS),* Island of Kos, Greece, May 2006, pp. 4090–4093.

[4] http://en.wikipedia.org/wiki/Discrete_wavelet_transform

List of Acronyms

SOI	Signals of Interest
SNR	Signal to Noise Ratio
Pd	Probability of Detection
Pf	Probability of False Alarm
CWT	Continuous Wavelet Transform
DWT	Discrete Wavelet Transform